REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 21 June 1993	3. REPORT TYPE AND DATES COVERED Final 1 Jul 89 - 30 Apr 93

4. TITLE AND SUBTITLE
Communication in the Presence of Unknown Interference

5. FUNDING NUMBERS
DAAL03-89-K-0130

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 27028.6-CC

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
A brief summary is presented of results obtained during the final period (1 July 1992 to 30 April 1993) under Grant DAAL03-89-K-0130 sponsored by the Army Research Laboratory and the Army Research Office. This report complements earlier reports which summarized the first three years of research under this grant. The research covers list decoding for jammed channels, multiple-access channels with jamming, random-access for channels with large propagation delays, and coding for multiple-access channels.

14. SUBJECT TERMS
Jammed Communication, Multiple-Access Communication, Random-Access Communication

15. NUMBER OF PAGES
6

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

COMMUNICATION IN THE PRESENCE OF UNKNOWN INTERFERENCE

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Final Report
u-der
Grant Number DAAL03-89-K-0130
for period
1 July 1989 - 30 April 1993

Prepared for

Electronics Division
Department of the Army
United States Army Command
Army Research Office
P.O. Box 12211
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21 June 1993

I. Research Goals

The overall aim of this research program was to investigate communication over point-to-point and multiple-access channels that are plagued by interference with an incomplete statistical description. Research efforts focused on two main objectives. The first objective was to develop and analyze robust communication techniques for the *arbitrarily varying channel* (AVC), which models a communication channel that is subject to intelligent and adaptable jamming. The second objective was to investigate the use of coding in multiple-access channels to mitigate the effects of co-channel interference and jamming.

II. Summary of Results

This section briefly summarizes the main results obtained during the period 1 July 1992 - 30 April 1993, which are contained in references [18-24]. Results in references [1-17] have been summarized in earlier progress reports.

List decoding: The arbitrarily varying channel models a communication channel that is corrupted by an intelligent jammer that adapts to all aspects of the communication system except those which are generated at random (or pseudo-random, in practice). To approach the capacity of this channel, the transmitter and receiver typically must employ synchronous random number generators for signal randomization [2,6]. Direct-sequence and frequency-hopping modulation can be regarded as practical examples of communication systems that use synchronous random number generators. In [18], we show that this signal randomization is unnecessary if *list decoding* is permitted. In list decoding, the receiver narrows the transmitted message to a small list of L possible messages instead of uniquely identifying it. Corresponding to each channel, there is a smallest list size L^*. If the receiver is permitted to employ list decoding with list size L^*, then *no signal randomization is needed.* The practical significance of this observation is that when list decoding is permitted on a jammed channel then, from the standpoint of channel capacity, there is no benefit in using synchronized pseudo-random number generators.

Multiple-access channels subject to jamming: TDMA and FDMA are efficient methods for sharing a radio or satellite channel among many non-bursty users. However, the time and frequency localization inherent in these schemes can be exploited by an intelligent jammer. This jamming vulnerability can be eliminated if users switch to code-division multiple-access (CDMA), but at the cost of increasing multiple-access interference. What then is is the best way to share a jammed multiple-access channel? In [21], we seek an answer to this question using information theory. We determine the capacity region of the multiple-access AVC, when all transmitters and the jammer are constrained in average power. For this channel, we show that the classic time and frequency sharing techniques are highly suboptimal. As a consequence, the capacity region is not a convex set. In related work [24], we show that the capacity region of the multiple-access AVC can be significantly increased by allowing all transmitters to share a common synchronous random number generator.

Random access with large propagation delay: On high-speed optical links, the propagation delay can be very large in comparison to packet transmission time (or slot length). For example, a packet of 1000 bits transmitted at a rate of 1 Gb/sec over an optical fiber of length 150 km will encounter a roundtrip propagation delay of approximately 1000 slots. Traditional random access schemes, such as ALOHA, were developed with the satellite channel in mind, where feedback propagation delay is on the order of 12 slots. It is therefore important to develop new random access schemes that are suitable for the shared optical channel. In [20] and [22], we consider random access to a packet broadcasting channel with long propagation delay. We introduce and analyze a new channel access protocol that combines aspects of ALOHA random access with the use of error-control codes across transmitted packets. Our results show that the use of coding in a random access scheme has a profound effect on throughput, delay, and stability. As in ALOHA, our system often has two stable operating points: one corresponding to high throughput and low backlog, and the other corresponding to low throughput and high backlog. As the blocklength of the error-control code is increased at a fixed code rate, the desirable operating point tends to still higher throughput and lower backlog, but at the expense of increasing the "basin of attraction" of the undesirable operating point.

Coding for multiple-access channels: Wolf posed the following problem for the multiple-access channel: How should codes be assigned to a collection of M potential users of a multiple-access channel, where it is expected that no more than $T \leq M$ of the users are active at the same time? Wolf further distinguished between two approaches to this problem. In the *static* approach (which requires no feedback), each of the M users is assigned a fixed code to use whenever active. In the *dynamic* approach, only T codes are used; when users become inactive their codes are reassigned to newly active users (thereby requiring feedback). In [19] and [23], we derive fundamental bounds on the performance of codes for the static assignment problem. Among the conclusions of this work is the observation that when $T \ll M$ (the typical case in practice), there is no benefit to synchronizing the users of a multiple-access channel.

III. Personnel

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Publications Supported by ARO Grant

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5. T. G. Thomas and B. Hughes, "Random modulation and arbitrarily varying channels," Presented at the IEEE International Symposium on Information Theory. San Diego: January 1990.
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20. R. Murali and B. Hughes, ''Coding in random access systems: throughput, delay, and stability,'' *Proceedings of the 1993 Conference on Information Sciences and Systems*, Baltimore, Maryland: March 1993.

21. J. Gubner and B. Hughes, ''Nonconvexity of the capacity region of the multiple-access arbitrarily varying channel subject to constraints,'' submitted to the *IEEE Transactions on Information Theory.*

22. Murali, R. and B. Hughes, ''Random access under large propagation delay,'' to be submitted to *IEEE Transactions on Communications.*

23. Y. S. Liu and B. Hughes, ''Multi-rate codes for multiple-access channels,'' to be submitted to the *IEEE Transactions on Information Theory.*

24. J. Gubner and B. Hughes, ''Dependent codebooks can increase capacity,'' to be submitted to the *IEEE Transactions on Information Theory.*